Research Article

Social learning lessons from Collaborative Adaptive Rangeland Management

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On the Ground

- As "co-produced" research becomes more popular, there is a need to evaluate the processes and outcomes of successful cases.
- The Collaborative Adaptive Rangeland Management project is a case of a ranch-scale, 10-year grazing experiment ongoing in Colorado. We used social science to evaluate group learning.
- We describe the complex, challenging aspects of the collaborative process, and how those challenges helped inspire learning as the team grappled with new problems and knowledge.
- Respect, trust, and shared understanding are essential to success.
- Social science can help collaborative research teams better design and implement complex co-production methods to engage stakeholders.

Keywords: Co-production, Participatory research, Grassland, Shortgrass steppe, Research evaluation

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Introduction

There is growing attention to collaborative research methods that better connect researchers and managers in rangeland ecosystems. Knowledge co-production engages multiple types of stakeholders with different knowledges to address complex and uncertain problems.[1] The USDA-ARS Long-term Agroecological Research network (LTAR network) is an opportunity to evaluate the ecological, social, and economic impacts of innovative, aspirational systems of food production and land management. In rangelands across the US West, different groups of people have various goals, knowledge, and preferences for management systems and practices. Various groups have different historical relationships and attitudes toward rangelands and experience multiple types of risk in relation to decisions on working landscapes. Here, we evaluate the Collaborative Adaptive Rangeland Management (CARM) project (Fig. 1), one example of how participatory social science can help researchers and nonscientist research partners advance our knowledge of the trade-offs and synergies associated with managing landscapes for multiple goals.

The CARM project is located at the Central Plains Experimental Range (CPER), near Nunn, Colorado, in the semiarid shortgrass steppe ecosystem. Adjacent to the USDA Forest Service Pawnee National Grasslands and conducted in collaboration with the oldest grazing association in the U.S., Crow Valley Livestock Cooperative Inc., CARM is designed to have immediate relevance to ranching, conservation, and rural communities in the western Great Plains. The semiarid shortgrass steppe evolved with large ungulate grazing, inter-annual variation in precipitation, and periodic fires. As a result, the plant communities are very resistant and resilient to grazing, and respond relatively slowly to management.[2,3] This region is experiencing land use, socioeconomic, ecological, and climatic changes that are reshaping rangelands and associated rural communities.[3] The CARM case study provides a concrete example of how participatory approaches can be integrated in a living laboratory to inform other teams and communities interested in exploring a collaborative adaptive management (CAM) model.[1]

The CARM project helps us understand the contributions of human dimensions and adaptive management to the outcomes of rotational grazing approaches.[4–6] Collaborative adaptive management expands upon formal adaptive management to incorporate multiple, diverse stakeholders and their different interests, ways of knowing, and accumulated

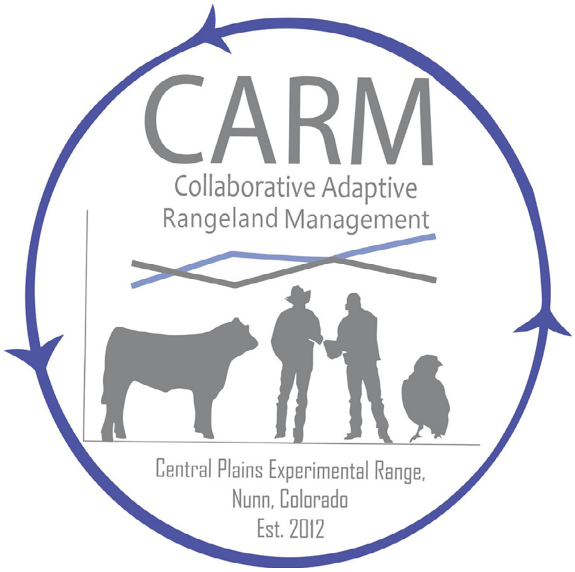

Figure 1. The CARM experiment brings managers and researchers from different backgrounds together in a ranch-scale, 10-year collaborative adaptive management project.

knowledge and wisdom into the adaptive management team and process. Formal adaptive management emerged to address resource managers' need to take action when knowledge of a system and management outcomes is incomplete, creating uncertainty.[7] With the twin goals of progress toward management objectives and learning (to reduce uncertainty), adaptive management relies on an iterative cycle of learning that includes assessing the system, setting clear and measurable management objectives, designing and implementing management experiments, rigorous monitoring, and evaluating outcomes in relation to objectives. However, adaptive management has proved challenging to carry out in practice[8] and more complex than the simple sequence just described.[9] One limitation of early adaptive management attempts was the failure to include all of the people who have relevant knowledge about the system, or who influence or are affected by management choices.[10] CAM remedies this weakness by making collaboration with a wide range of relevant stakeholders a key element of the learning cycle.[9]

Engaging stakeholders in CAM via a transdisciplinary[11] approach has multiple potential benefits, including 1) greater understanding of and buy-in for management decisions by collaborating partners; 2) inclusion of diverse knowledge and the potential for innovation; 3) opportunities for shared learning and wider diffusion of new knowledge through practitioner communities; and 4) increased trust, relationship building, and new networks among participants, including researchers and professional partners.[10] Partners in the CARM project included researchers from rangeland ecology, hydrology, and sociology working in an integrated fashion with professionals from various sectors of society, including agriculture, government, and nonprofit organizations, as co-equal participants on a research team.[12]

In the following sections, we describe a case study of knowledge co-production using CAM and show the value of transdisciplinary research for rangeland management. First, we describe the CARM project design overview, including a summary of findings to date. Second, we synthesize findings related to the project's social learning objectives, including evaluation methods, social learning evidence, and gaps and challenges associated with each objective. Finally, we conclude with insights, opportunities, and recommendations for future collaborative science projects.

CARM experimental design overview

CARM is a long-term, ranch-scale, participatory grazing experiment evaluating the effectiveness of CAM on rangelands for both production and conservation goals.[13] The ecological context and decision-making process of the CARM group are described elsewhere.[9,12–14] We provide a high-level overview related to the experimental design involving social science. The project includes an 11-member "Stakeholder Group" (Table 1). This group uses an iterative and collaborative adaptive management process to set goals and objectives (Table 2), apply management treatments, and adapt management within and among years as new information, knowledge, seasonal weather forecasting, and monitoring data become

Table 1. CARM stakeholder group members represent conservation, ranching, and state and federal organizations.

Organization	Representative(s)
Bird Conservancy of the Rockies	Angela Dwyer (current) Seth Gallagher Gillian Bowser
Environmental Defense Fund	Ted Toombs
The Nature Conservancy Colorado	Terri Schulz (current) William Burnidge
Crow Valley Livestock Cooperative Inc.	Dana Bowman (current) Andy Lawrence (current) Steve Anderson (current) Jeff Wahlert (current) Leonard Ball Jason Kern Scott Timm
USDA Forest Service	Stephanie Magnuson (current) Kim Obele
USDA Natural Resources Conservation Service	Rachel Murph
Colorado State Land Board	Matt Pollart
Colorado State University Extension	Annie Overlin (current) Donald Schoderbek Casey Matney

CARM indicates Collaborative Adaptive Rangeland Management; USDA, xxxx.

Table 2. The CARM Grazing Management Plan is driven by the overarching goal "to pass the land on to future generations, economically and ecologically," and is accompanied by objectives for vegetation, profitable ranching and wildlife outcomes. These were established in 2012 and revised in April 2018. Stakeholders agreed to strive for all objectives, and to always evaluate the impact of any decision on all objectives before voting on a proposed action. Social objectives were added in 2015 and are addressed in Fig. 3

Vegetation	Profitable ranching	Wildlife
Attain and/or maintain abundances of cool-season perennial graminoids within 30% of targets for each plot[5]	Maintain or increase revenue in CARM relative to the revenue generated under TRM within a given year[5,20–22]	Increase populations of mountain plover
Maintain or increase plant compositional diversity both within and across pastures	Reduce negative consequences of drought on the CARM herd and other objectives	Maintain high quality breeding habitat and high densities of thick-billed longspur[19]
Increase variation in vegetation structure, composition, and density within and among pastures	Maintain or reduce operating costs in CARM relative to TRM[21]	Maintain high quality breeding habitat at high densities of grasshopper sparrow[19]
Increase or maintain cover relative to baseline in pastures that had stands of four-wing saltbush at the start of experiment		Maintain control of prairie dogs

Note: CARM indicates Collaborative Adaptive Rangeland Management; TRM, traditional rangeland management.

available (Fig. 2). The collaborative element brings together multiple social worlds and ways of knowing.[9] The Stakeholder Group includes ranching, conservation, and land management expertise. This group uses a consensus-based decision-making process.[9] The Stakeholder Group meets with researchers quarterly and engages the transdisciplinary research team from ARS and several universities for input in decision-making, as well as assistance in analyzing, interpreting, applying, and communicating the findings to other managers (Table 1, Fig. 2). The research team initially included individuals with expertise in rangeland and wildlife ecology, animal science, and human dimensions, and now includes those with economics, climate and weather adaptation, hydrology, and systems modeling expertise to address new questions.

The CARM group first came together in 2012 to set project goals, make an initial grazing management plan and establish the overarching goal to "pass the land down to future generations (ecologically and economically)."[13] They agreed on objectives related to grassland plant community composition and heterogeneity, grassland bird conservation, and profitable ranching, including drought resilience. Later, the group added explicit social learning objectives (Table 2) and agreed that all stakeholders would work together to reach all objectives, regardless of their individual interests. Baseline data were collected in 2013 with experimental treatments initiated in 2014, based on a grazing management approach the team hypothesized would optimize their objectives. The group has added and revised individual objectives at different times over the past 8 years,[12] and has also continually compared outcomes from the CARM herd and pastures to 10 "status-quo" pastures grazed by a second herd of steers at the same ranch-scale stocking rate and receiving the same vegetation treatments. The comparison of two alternative grazing treatments with the same system-level stocking rate, a ranch-scale experimental design, and pairing of pastures controlling for soils/ecological sites, plant communities, and topography overcome several prior criticisms of grazing system scientific studies.[4,5]

"Aspirational" and "business as usual" treatments

The experimental design of CARM follows the LTAR network common experiment format, comparing an "aspirational" versus a "business as usual" treatment. The group designated a "business as usual" treatment as "Traditional Rangeland Management" (TRM), with 10 separate herds of yearling steers, each grazing a half section (320 acres or 130 hectares) from mid-May to early October. This mirrors local management common on the Pawnee National Grasslands and private ranches throughout the area where cattle graze under a season-long, continuous grazing system, which has been employed for decades.[13] For the "aspirational" treatment, the Stakeholder Group decided to combine the 10 separate herds of yearling steers into one large group and then rotated them using adaptive thresholds for movement among 10 pastures that were paired with and equal in size to the 10 TRM pastures. Each year, the group selects stocking rates (same for both the TRM and CARM treatments), triggers (adaptive thresholds) for movement of livestock between pastures, the sequence of pastures, additional vegetation management treatments such as prescribed burns, how many and which pastures to rest, and triggers to implement a drought plan.[14] For example, the initial grazing management plan included plans to rest at least two different pastures annually to improve grass banking for drought, vegetation heterogeneity to support grassland bird habitat objectives, and cool-season grass production.

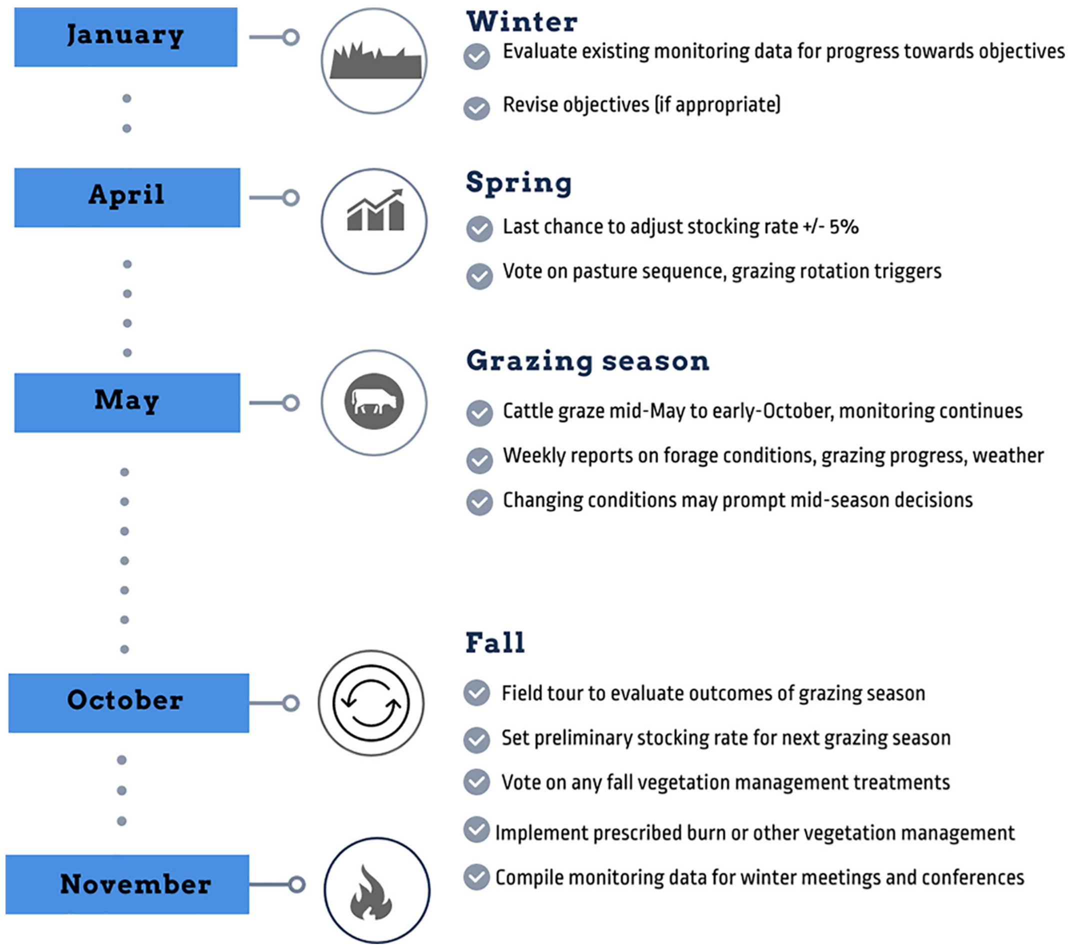

Figure 2. Generalized annual decision-making process for the CARM Stakeholder Group. Specific decisions are documented most recently elsewhere.[5,8,11,12]

In addition, the group developed pasture-specific objectives after a few years as they learned how pasture characteristics may be used to optimize objectives and reduce trade-offs in multiple goals over space and time. For example, specific pastures dominated by the Loamy Plains ecological site supported higher densities of a grassland bird species of concern, the thick-billed longspur (*Rhynchophnes mccownii*, formerly McCown's longspur), and hence received grazing management designed to enhance habitat for this species. Stakeholders refined these pasture priorities iteratively through ongoing data collection, evaluation, interpretation, and management implementation within a continuous collaborative adaptive management process.

The presence of the TRM treatment offers an advantage over previous case studies of adaptive management outcomes at the ranch scale because it serves as an unreplicated "control." In other studies of rotational grazing, scientists have not controlled for stocking rate, so reported increases in cattle production may have been because of expertise in adaptive management or higher stocking rates in rotated herds.[4,5] The CARM project's design allows the team to control for the effects of ranch-scale, seasonal stocking rate. It also largely allows us to control for grazing season, soils, ecological potential and other characteristics of the grazed land, stockmanship, climate and weather, water infrastructure, the experience and skill of people who selected pasture shape, prescribed fire treatments, and the genetics of the cattle, because these aspects of the project are effectively the same on both sides of "the fence." The major differences between the two treatments are derived from the presence of a collaborative group, and their decisions that included shifting density of the cattle, the sequence of pastures grazed, the ecological indicators used to trigger herd rotation among pastures, and pasture rest periods.

Social science in CARM: A whole new world

CARM marks the first time that ARS researchers at CPER gave a team of customers decision-making power directly in a grazing experiment. Despite numerous collaborations among USDA-ARS and university researchers, and the Crow Valley Livestock Cooperative, Inc., which has provided cattle for every grazing experiment, stakeholders had never been previously involved in all aspects of a grazing research project at the CPER. It was also the first time this ARS unit collaborated with qualitative natural resource management social scientists, who provide methodological tools for addressing whole social-ecological system questions. We also note that CARM is the first ranch-scale, decade-long grazing experiment conducted at the CPER addressing both agricultural production and biodiversity conservation objectives. Although various stakeholder organizations in the project brought different motivations and goals for rangeland management to the station, and individuals at the table had a wide spectrum of collaborative, educational, and professional backgrounds, they reported coming in with an open mind and a desire to learn. Hallmarks of the new approach include the participatory involvement of diverse stakeholder goals and decision-making in co-produced social-ecological research at management-relevant spatial and temporal scales. In other words, CARM is a whole new world.

This complexity fostered learning, and we adapted our methods to the CARM context.[8] For example, social science projects traditionally recruit participants under the agreement that their identities will remain confidential. However, the stakeholders took a great deal of ownership over the project and findings. As a result, we modified our university-approved human research protocol and updated the consent process to allow stakeholders to gain credit for co-authorship on scientific articles.

When social scientists set out to engage in this "new world" of CARM, we faced a dilemma—what was our position in the project? One approach was to take a position outside of the project, looking inward to conduct research "on" the CARM participants. This type of research might include a series of systematic learning interventions and evaluations building basic knowledge of how groups learn and collaborate. The second approach was to participate as active team members, doing research "with" all participants in a transdisciplinary spirit that recognized all group members as colleagues. We chose the second approach for several reasons. First, the CARM Stakeholder Group was small (11) and not randomly selected to represent any particular populations. Therefore, we could not generalize learning outcomes to broader insights for educational psychology literature, for example, but could use case study methods to derive important insights for the CAM process.[15] Second, this approach to process was likely to build the most trust. The science team and Stakeholder Group recognized that they had grown increasingly close professionally and personally as the CARM project developed, and often collaborated outside of CARM. The social science team was invested in advancing social learning in CARM, but not interested in operating in a fishbowl. We wanted to avoid a situation where meeting attendees felt they were serving as "guinea pigs" for their own colleagues. As a result, the social science team actively participated in collaborative roles for project strategic planning, facilitation of meetings, Stakeholder Group engagement, evaluation of biophysical and ecological science data, all while leading the social science evaluations. Biophysical and ecological scientists engaged with the social science team to learn about social science concepts and methods, and co-authored social science papers.

We developed social learning methods by drawing first on a body of work from around the world that is emerging to evaluate outcomes in this unique transdisciplinary space. This included Caves et al.'s six criteria for assessing the effectiveness of CAM as follows: 1) reducing ecological uncertainty, 2) achieving desired management outcomes, 3) using monitoring data in adaptive decision-making, 4) including multiple stakeholder interests and perspectives, 5) building trust and collaborative capacity, and 6) multiple-loop learning.[16] This framework enabled us to develop our assessment of the CARM social learning objectives in 2015 (Fig. 3).

We also relied on Wall et al.'s co-produced science evaluation framework.[17] This framework for developing and evaluating co-produced research draws heavily from the literature and from interviews with climate science professionals. It includes 45 indicators in the categories of a) context, b) process, and c) output, outcome, and impact indicators of successful science co-production. For example, Wall et al. note that outputs of research often include a number of publications or workshops, and a commonly sought outcome of applied research is "behavioral change."[17] The framework includes various aspects of the collaborative process that are also important to success, such as resolving challenges in mutually agreeable ways, and evaluating multiple forms of information use as indicators of impact, ranging from better

Figure 3. CARM social learning objectives (bold) and key indicators (bullets) were established by the stakeholder group after evaluating early decision-making.[12]

comprehension of a particular problem to conformational or motivational use of information.[17]

We considered this framework when we developed CARM indicators for the various social-learning objectives and our qualitative monitoring of the CARM learning process and outcomes (Fig. 2). Qualitative data included audio recordings and notes from meetings and tours, collections of research products (i.e., presentations, posters, fact sheets, and details about outreach events), and written worksheets or correspondence among team members.[9,12] It also included specific reflective sessions with scientist and stakeholder groups, and reflective field notes from individual researchers submitted to an online form.[12] For some indicators, we used charts to record the specific grazing and vegetation management decisions made by stakeholders during the grazing experiment, and recorded their justification for shifts in stocking rates, pasture sequence, herd rotation schedules, and prescribed fire.[6] In other cases,[12,13] we coded notes or meeting transcripts to interpret motivations, emotions, and dialogue among group members. In qualitative data coding, researchers identify and mark chunks of text with descriptive labels that help us understand a specific phenomenon, like the quality of CARM processes and outcomes of specific events.[9,13] In the section below, we describe what aspects of CARM we used to assess progress toward the social learning objectives; what inputs, outputs and outcomes we observed; and key gaps and challenges.

Progress toward social learning objectives

Objective 1: Stakeholders and researchers co-produce new knowledge

What are we looking for to understand knowledge co-production? Indicators of success toward this objective boil down to those that track successful implementation of the project and progress of the collaborative science. These include goal setting, management action implementation, monitoring and evaluation, and adjustment.[16] We documented progress toward biophysical objectives, which we evaluated at each meeting and reported in presentations and peer-reviewed literature (Table 2). Core evidence of social learning also included management decisions based on project-derived information or discussion ("single-loop learning"), modifications to project objectives ("double-loop learning"[18]), and the associated ecological outcomes of these decisions, as manifest in meeting documents and peer-reviewed literature. We also sought to document evidence of "triple-loop learning," which occurs when participants revise values, norms, and structures that underlie assumptions and actions.[9] To trace these processes we examined dialogue and formal decisions about revision of goals, objectives, and group process.

We also adopted multiple indicators of co-production—evidence of collaborative development of project design, modification of objectives and indicators, team evaluation and application findings, and production of reports, presentations, and papers. These products often highlighted multiple types of knowledge and the ways in which group members learned about the objectives.

A process-tracing method allowed us to follow knowledge co-production over time. The CAM process was both nonlinear and complex, with time lags in data availability, path dependency, and trade-offs at multiple scales.[9] In the case of specific decisions, such as decisions about whether or not to apply prescribed fire, qualitative data was helpful in describing challenges associated with integrating situated local knowledges and experimentally derived knowledge.[13] Even when presented with data that indicated benefits of prescribed burning to cattle production, biodiversity conservation, and vegetation heterogeneity objectives, ranchers voted not to use prescribed fire in the first years of the project. As described elsewhere,[13] they relied more heavily on their experiential knowledge of risk and scarcity of forage in this drought-prone rangeland. This demonstrated how including multiple types of knowledge in CAM does not easily reconcile differences among scientific information and a practitioner's preferred management style or practice.[13] We also discussed double- and triple-loop learning as these types of learning emerged from a process of objectives revision.[12] In this process, stakeholders and scientists drafted new, more spatially and ecologically specific objectives based on learning that occurred early in the project. We also reflected on the "big picture" of conservation and ranch resilience objectives and participatory research in this setting.

Peer-reviewed papers reported on learning about ecological relationships and management outcomes in the CARM context, one of the core indicators of successful CAM and social learning objective 1. Six years into the project, these insights included the following:

- Evaluation of the CARM treatment's ability to impact the abundance of grassland bird species with contrasting nesting habitats.[19] Results helped us understand the spatial specificity of managing for these species, and later helped us refine objectives for individual pastures by accounting for site fidelity of these grassland birds and trade-offs between suitable bird habitat and plant diversity objectives.
- Vegetation outcomes did not differ between grazing treatments, but cattle weight gains were consistently 12% to 16% lower in CARM relative to TRM.[6]
- To quantify the contribution of adaptive management (i.e., the groups' selection of pasture sequence and grazing rotation indicators) to outcomes for cattle weight gain, comparisons were made to a third herd of steers rotated in a randomly determined sequence (i.e., without adaptive management). This comparison indicated that weight gains of adaptively managed cattle were 23% to 25% greater than gains expected under purely random rotational grazing management.[19]
- Economic evaluations were completed for cost of fencing and water infrastructure, and labor, revealing that

continuous (TRM) and multipasture rotational (CARM) were the least and most costly management scenarios, respectively.[20] Economic analyses that included long-term market conditions and fluctuations in cattle prices during the seasonal cycle showed that net returns were greater for TRM cattle in 3 of 5 years, equivalent for CARM and TRM in 1 year, and greater for CARM relative to TRM in 1 year.[21]

One of the key challenges of co-production is to create a research context that is meaningful for researchers and managers, who may have very different data needs and interests. Our assessment of progress toward Objective #1 is informative for this challenge. As the CARM project progressed, the roles of stakeholders and scientists shifted over time, and new opportunities to integrate local and professional knowledge, new ways to ask questions, and more in-depth discussion of research findings emerged. These shifts are also evidence of progress toward social learning objective 1. One example is found in a "side-experiment" led by Dr. Lauren Porensky in response to a hypothesis that the CARM stakeholder group described related to rotational grazing management. This study evaluated the stakeholder hypothesis that compared with continuous grazing, rotational grazing will lead to less frequent defoliation (less regrazing) of individual grass tillers. In another example, graduate student Jessica Windh engaged stakeholders in a series of discussions to revise the profitable ranching objectives. During this time, rancher Steve Anderson developed his own financial analysis of the CARM herd and presented this to the group. Mr. Anderson's analysis along with Ms. Windh's research findings led to discussions of how to assess financial outcomes in the project from multiple perspectives and provided valuable insight into a rancher's interpretation of cattle production outcomes and management. This example led to a broader discussion of the role and methods of economics research and how an approach to assessing profitability by modeling outcomes in the long-term cattle market[21] differs from the accounting approach taken by the ranchers. For example, analysis using historical data sets to show the potential range of outcomes of "what could happen" seemed to be more important to some of the stakeholders, while "what did" happen in the most recent year seemed most important to others. Further, a lot of economic concepts and theories, and market phenomena, such as the price slide (the fact that the price per unit of weight tends to decrease as animal weights increase) were not commonly understood by most stakeholders. Ranchers tend to sell all of their animals at a single place and time, therefore receiving one "price" for their cattle and so do not often consider the impact that weights have on prices. Many other stakeholders are simply unfamiliar with livestock marketing channels in general. We offer these as examples of coproduced knowledge that furthered research and management learning goals.

Gaps and challenges with co-production-The team faced multiple challenges to achieving the first objective. Throughout the CARM process, researchers have been responsible for the data collection, data management, and report-out processes. As a result, they have had primary access to ecological and social data and have spent a lot of time thinking about and interpreting these data, often before or in preparation for meetings with stakeholders. Researchers have often struggled with how to communicate with stakeholders about monitoring data and interpretations without co-opting the process, overemphasizing their own knowledge of the data or feelings about an objective, or omitting key results or insights. This challenge to co-production is ongoing, and although it could potentially be alleviated if stakeholders had more time to engage with participatory data collection and interpretation, the current stakeholder group does not have this much time to dedicate. Thus far, CARM stakeholder commitment has been strong, but higher turnover or lack of professional interest could pose a significant challenge for the collaborative learning process.

The team also had to develop a process to analyze and interpret results that would ensure dynamic and adequate examination of findings so that the impact of management decisions was considered for all objectives. This process was generally successful in CARM due to growth in our facilitation capacity that developed as stakeholders and new researchers shared their expertise in this area. This is a vital and often underrated role in the process. Facilitation serves many purposes, including keeping the group on track and moving the project forward.

The project has not yet documented strong evidence of triple-loop learning in relation to the over-all goals and motivations of the CARM project. Although the team explicitly discussed the above challenge related to time limitations and agreed upon scientist roles to advance the CAM process,[11] other reflections upon or adjustments to the CARM process and goals have been more incremental over time. There is more opportunity to advance triple-loop learning by reflecting on the assumptions, values, and norms of the project in the years to come, especially as biophysical lessons become clear.

Objective 2: Share and apply new knowledge and CARM in new areas

How do we know if CARM has been applied successfully in new areas? As Wall et al. note, researchers often hold up broad adoption of their findings and direct behavior change as the ultimate indicators that their work was impactful[17]. This is called instrumental information use. However, other outcomes related to information use also should be considered. These include conceptual information use, when an organization or individual is better informed about a topic or decision, and justification use, where new information justifies an existing decision.[16] We used qualitative tracking of team activities and products to help us document progress toward this objective. Here, we highlight key examples of multiple products and outcomes.

First, stakeholders and researchers have co-presented numerous field tours for the public and university classes. Second, the full team developed and co-presented at a symposium on the CARM project at the 2018 Society for Range Management meeting in Sparks, Nevada. This half-day symposium featured ranchers, conservation group and agency representatives, a short film about the project, and facilitated discussion with the audience. Third, a series of fact sheets about shortgrass bird responses to rangeland management was developed by the research team and graduate students. Terri Schulz, from The Nature Conservancy, and Angela Dwyer, from Bird Conservancy of the Rockies, distributed these manager-friendly publications to ranchers and managers throughout Eastern Colorado. Fourth, research findings and the participatory approach have been highlighted at annual LTAR meetings. Fifth, this project was used as a case study in a report on Agroecosystem Living Laboratories presented to the G20 Chief Scientists in 2019[2] as well as in the Fourth National Climate Change Assessment.

Collectively, the outcomes to date on this project have also influenced the trajectories of other research projects. For example, our colleague in Nebraska, Mitch Stephenson, received funding from NRCS to engage ranchers there in a CAM project that will include collaboration and knowledge sharing with the CARM team. Research efforts addressing impacts of prairie dogs on rangelands in northeastern Wyoming were developed with similar participatory involvement of numerous stakeholders and addressing the full social-ecological system. Bird Conservancy of the Rockies, a nonprofit and stakeholder member is implementing a large-scale grassland bird monitoring project on ranches using rotational grazing. Bird Conservancy of the Rockies is also contracting with the University of Wyoming for an economic analysis portion of that project; further, they are implementing a series of partner meetings for participatory alignment.

Gaps and challenges with extending findings-There are a number of ongoing challenges related to this objective. CARM team members have dedicated time and attention to developing symposia, field tours, and presentations to help make the public and the rangeland management community aware of our findings. However, expansion of CARM ideas beyond these activities has only occurred "organically," without a larger strategic plan or funding to conduct extensive outreach. Next steps for this objective may be to seek funding and programming to explicitly target and evaluate specific audiences with educational and outreach activities through Land Grant, Society for Range Management, and nonprofit partners. Wall et al.[17] make the important point that existing structures of assessing scientific "success" (which typically focus on reporting the number of peer-reviewed publications or amount of grant money received) are poorly adapted to evaluating new forms of transdisciplinary, co-produced science aimed at making change in the world. This is especially relevant when the desired change is outside of academia and government agencies. Additionally, documenting instances of traditional "technology-transfer" (such as patents) may not account for the work aimed at tackling complex rangeland, forestry, or natural resource problems that are not primarily technical.

Objective 3: Respect. understanding, and trust increases among stakeholders and researchers

How do we know if CARM has led to enhanced respect, understanding and trust among team members? To assess progress toward this objective we sought evidence of 1) the full team's commitment to and valuing of the project, 2) discussions and activities demonstrating that various members were learning to recognize and even advocate for one another's points of view, and 3) instances where CARM team members collaborated or networked outside of the CARM project. We used meeting transcripts, interviews, focus groups, and informal check-ins to document these outcomes.[9,12,13] Monitoring team members' self-reported interest in the project and trust in one another was important to sustaining the project over the first 6 years as the science team facilitated the CAM process. Afterall, trust may be a prerequisite to other social learning outcomes.[12]

Trust and respect among members of the full CARM team (both stakeholders and researchers) took several years to build (Fig. 4). The initial meeting in 2012 resulted in a shared overarching goal and objectives, but the full team had to learn how to operationalize management toward that shared vision through multiple grazing seasons. With time, strong working relationships among group members became more effective and efficient for both decision-making and communication. Now, individual Stakeholder Group members lead discussions and decision-making processes more frequently. Conversations and discussions have more depth and breadth, encompassing understanding of motivations, viewpoints, and expertise with more focused and probing questions. At a focus group meeting in 2019, the whole group reflected on our community of practice, or "CARM family," reporting that learning from one another and collaborating was one of the

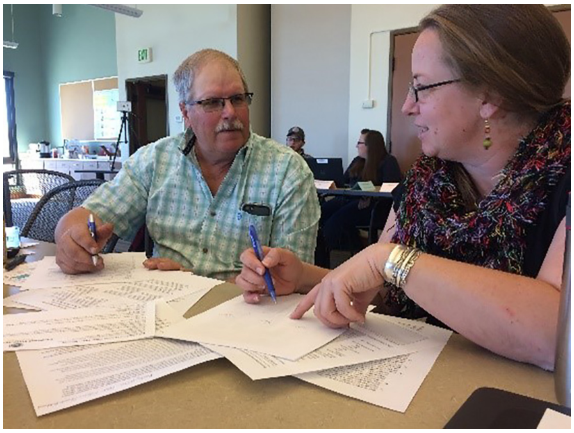

Figure 4. Crow Valley Livestock Cooperative, Inc., representative Steve Anderson works with NRCS Colorado State Rangeland Conservationist Rachel Meade to interpret CARM data (Photo taken by H. Wilmer).

most important reasons they continued to engage with the CARM project. That year, the summer meeting included a tour of one of the working cattle ranches owned and operated by a rancher stakeholder, rather than focusing directly on the CARM treatments. During this ranch tour, the group members discussed the future of ranching, challenges to ranch viability and rural communities, and deeply personal and family-related challenges associated with these goals. This honest and open conversation demonstrated the trust and respect the team had developed over time.

Social scientists also observed that trust, respect, and understanding among stakeholders led to some changes in decisions. Early in the project, ranchers in the CARM group voted against prescribed burns based on their intergenerational knowledge and views about fire. More recently, ranchers supported prescribed fire when conservation and agency members proposed a burn to learn about its impacts on cattle weight gains, though they could not do so without sharing a laugh. This decision-making process illustrates both how conservation and agency staff showed concern for rancher interests (e.g., cattle weight gain), and how ranchers demonstrated trust in other stakeholders and in the CARM process as a way to create new and useful knowledge together, even about potentially risky practices.

Gaps and challenges with enhancing trust, respect, and understanding-We acknowledge that certain aspects of the CARM project limited our ability to evaluate this objective. First, the CARM project takes place in a social-ecological setting with relatively less conflict than other settings, and participation was not open to the public. With this design, the project did not recognize or include various forms of conflict and historical context that would have otherwise shaped trust outcomes. It is also possible that stakeholders may have self-reported increased respect and trust, while actually having reservations or concerns they did not share (social acceptability bias). The fact that we were all bound together in the scientific, collaborative, and evaluative processes does, therefore, limit our ability to report on this objective. Second, the team initially undervalued the contribution that facilitation skills and collaborative methods would bring to the project, which led to confusion and tensions in early meetings. Team discussion and learning led to more clarity around these roles and expectations for meeting structure. Explicitly recognizing the role of conflict and addressing it is not common in traditional agricultural research and may feel especially uncomfortable or irrelevant to the outcomes of a project. However, it is not to be ignored, as it can shape the experience and outcomes of the project for many invested stakeholders. Third, because the project took place in an experimental setting where the land was not owned by any of the stakeholders, they may have felt less of a vested interest in the outcomes. This may have allowed greater scope for risk taking and learning than might be the case in other settings, and thus is both a strength and limitation of CARM. We recognize that our ability to sustain trust and respect have largely relied upon our ability to physically interact on the landscape during field tours, or while sharing food and informal networking opportunities at day-long meetings.[12] Although there has been some turnover in stakeholder group membership, the majority of the members have remained the same in the past several years. The coronavirus 2019 pandemic has created new and unexpected challenges in holding the "CARM family" together, though project staff are working to rise to the occasion via virtual field tours and meetings.

Discussion

CARM is a novel approach to engaging manager communities into rangeland management research. Six years into experimental treatments, CARM has made progress towards all three social learning objectives. We were able to evaluate 1) how well CARM modeled and tested aspects of the CAM structure where new ideas can be experimentally evaluated, and 2) to what extent the CAM process can be used as a tool to build capacity, social learning, and trust within a specific community of practitioners, researchers, and students. The following are our three main lessons and outcomes:

- Stakeholders and researchers successfully implemented a collaborative adaptive management method to co-develop new knowledge about social, economic, and ecological questions in CARM (social learning objective 1). This process was often complex and challenging, but those challenges helped inspire learning as the team grappled with new problems and developed strong working relationships.
- The team continues efforts to share these lessons outside of the CARM project (social learning objective 2), though expectations that co-produced research will be transformational may not be well accounted for in traditional metrics of scientific success and impact. Stakeholder participants are important partners in disseminating research findings to different end users.
- Respect, trust, and shared understanding (social learning objective 3) are essential for collaborative processes and learning and can be enhanced by commitment and time for meaningful discussion, debate, and group reflection.

Although CARM is an example of a living laboratory within the LTAR network, this approach is not right for every site or community of researchers and practitioners. Other social science disciplines, such as sociology, economics, or social psychology, may rely on customer focus groups, choice experiments, surveys, or modeling approaches based on the needs of other research contexts. These methods can also be paired with participatory approaches. We also hope readers consider how co-production processes, like CARM, are not risk free. Even projects with good intentions can lead to disrespectful or problematic interactions with communities, especially if teams are inexperienced or ill-prepared for this new type of work. Researcher teams should carefully consider their capacity to follow through on partner engagement, considering multiple aspects of historical context, power, research ethics, and equity and justice as they design and implement their work. This may be especially important for researchers working in areas or with research questions that have more historical conflict. The CARM also had the benefit of leveraging existing research relationships with rancher collaborators, and selected participants from our known networks.

Researchers and managers considering collaborative or participatory research approaches in the future might glean specific insights from our experience, specifically the following:

- Knowledge co-production is a complex, time, and resource-intensive process that depends upon commitment to learning, flexibility, growth, and relationship building from individuals and organizations.
- Including team members with appropriate social science training and experience for the selected approach from the beginning enhances project success. These team members can help advocate for rigorous collaborative and evaluative methods and help teams limit risks to community participants. Nonsocial scientists are also key partners in advancing social learning objectives.
- Our knowledge of co-produced researcher processes is advancing rapidly. Teams interested in this approach have access to more empirical and methodological resources than ever before and may benefit from careful planning and reference to the evaluation, education, and related literatures.[9,15,16]
- Careful evaluation of evidence of both successes and barriers to success are equally important processes in this type of research. In the spirit of adaptive management, co-production methods can be adjusted to match the context of each research setting and needs of various manager communities, and iteratively as the project evolves.

The CARM model may be informative for multiple types of rangeland communities. For managers or landowners, CARM offers a model to engage science in management through adaptive or applied methods, and to connect with a larger network of conservation, agency, and research partners. For public lands management agencies, this model offers a structure for establishing and adapting multiple-use goals via collaborative processes, acknowledging multiple knowledges and forms of data, and comparing outcomes between aspirational scenarios and "status-quo" controls. CARM may offer insights and a process for public lands managers, private lands ranches or properties with absentee owners, stewardship alliances, cooperatives, or non-profit organizations seeking a methodology to get people learning together and connected on the landscape. Across these contexts, collaborative learning processes may offer professional development opportunities for persons from different backgrounds and experiences as they begin thinking, working, and learning together in an effort to build common ground, though context-specific adjustments will be necessary.

As co-production approaches gain traction in rangelands globally, it is important to engage evaluation methods to advance our understanding of social learning and associated collaborative process. This paper provides one example of how social science can contribute to an applied, participatory project focused on rangeland management research questions. Just as rangeland managers and ecologists have increasingly focused on the complex details of managing grazing distribution in space and time, the science and critique of collaborative science can push teams and communities beyond the yes/no question of whether to engage in participatory processes, to ask instead how to best design and implement these complex processes.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors certify that they have no financial interest in the subject matter discussed in the manuscript. J.D.D., L.M.P., and D.J.A. are employees of USDA Agricultural Research Service, and were associated with management decisions regarding the topic of this manuscript. M.E.F-G is a past SRM board member but was not involved in the review of decision process for this manuscript.

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